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ABSTRACT

A course in modeling and computer simulation of dynamic systems uses three methods to introduce students to these topics. Core studies, the consideration of the theoretical fundamentals of modeling and simulation, and the execution by students of a project are employed. Taught in the Electrical Engineering Department at Michigan Technological University, the course is broadly based with regard to both subject matter and simulation methods, and students are free to select a project in any area and to use the computer and language of their choice. Societal, scientific, and engineering models are studied, and digital, analog, and hybrid computer simulations are considered. The course is intended to increase the students' awareness of the possibilities of quantizing problems associated with dynamic systems and to inform them of the potentials of computer simulation. Design, rather than analysis, is emphasized and student projects aim at utilizing computer simulations to determine control strategies. Evaluation to date indicates that the course is both successful and popular, but also that students require additional training in generating project problems and in writing technical proposals. (Author/LB)

MODELING AND COMPUTER SIMULATION OF DYNAMIC SOCIETAL, SCIENTIFIC, AND ENGINEERING SYSTEMS

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A course in modeling and computer simulation of dynamic systems has been developed in which the student is introduced to the subjects at three levels: through case studies, through a study of theory fundamental to modeling and simulation, and through the execution of a complete modeling and simulation project. The course is broadly based with regard to both the modeling subject matter and the methods for implementing computer simulations. In selecting a project problem for modeling, the student is free to select any subject area; and in selecting a method of computer simulation, the student is free in his choice of computer and computer language.

The course emphasizes fundamental concepts and techniques underlying modeling and simulation which are independent of the subject area and the method of implementation. Thus societal, scientific, and engineering models are studied, and digital, analog, and hybrid computer simulations are considered.

The course is intended to increase the student's awareness of the possibilities of quantizing problems associated with dynamical systems both in and out of his area of discipline and of the many possibilities for computer simulation. Design, rather than analysis is emphasized. The student's main objective in his project is generally to utilize his computer simulation to determine a realizable strategy for control.

Preliminaries

The course in modeling and simulation is a ten-week, three-credit course meeting three times a week. It was offered for the first time in the fall quarter of 1972 in the Electrical Engineering Department of Michigan Technological University. Twenty-four electrical engineering seniors enrolled for the course; twenty students completed the course. The prerequisites for the course are the equivalent of four quarters of calculus, three quarters of physics, and some background in digital computer programming. Since the course was taught under an existing course number and description prior to formally introducing the course in the curriculum, the students taking the course had backgrounds typical of first quarter electrical engineering seniors. This was generally more than the minimal background suggested. The course does not depend on an electrical engineering background, and it is hoped that in the future other students will be encouraged to enroll.

No textbook was used for the course. However, the lecture notes and important papers from the literature were distributed to the students. Pertinent references were put on reserve in the library. A partial list of these references is given in Appendix I.

The grading system was designed so as to emphasize the completion of the modeling and simulation project rather than the passing of examinations based on a specified body of information. Accordingly, the course was divided into four grade units and the student received one point for the satisfactory completion of each grade unit: one point for a written project proposal, one point for a written report detailing the model, one point for a written report detailing the simulation and the simulation results, and one point for passing two quizzes. No final examination was given.

The ability of the student to communicate his ideas was an important factor in completing the course. Each student was required to submit a detailed proposal describing his project problem and his planned approach to it, two progress reports, and a final report. Each student was also required to make an oral presentation to the class describing his project and presenting his results. Students were permitted to collaborate on the modeling and simulation project provided they specified the division of labor in the initial proposal.

Course Structure And Syllabus

The main problem faced by the instructor in teaching a course such as this is one of sequencing of materials. As usual, there are conflicting objectives. If the student, by the

beginning of the fourth week, is to intelligently select a project problem, develop an approach to modeling it, suggest a satisfactory simulation scheme, and write a written proposal detailing all this, then it is clear that he must quickly gain perspective in the area of modeling and computer simulation. As satisfying and comforting as it may be for a professor to start at the beginning, carefully laying the foundations, etc., a strong case can be made here for starting with end results. This is what was done.

The first three weeks were spent going through modeling and computer simulation case studies. There was some attempt to deal with simpler systems initially, but the pressure to provide the student with the perspective necessary to begin his project did not always allow this. The case studies used were selected to illustrate the many kinds of systems (societal, engineering, scientific) that might be modeled, the variety of approaches that can be used for modeling (continuous time vs. discrete time, statistical vs. deterministic, aggregation vs nonaggregation) and the methods available for the implementation of simulations.

The students submitted their project proposals at the beginning of the fourth week. The proposals were promptly evaluated and returned.

During the fourth through the eighth week, theory fundamental to modeling and simulation was presented to the students through lectures and lecture notes. This included introduction to the concept of dynamic systems. State was defined and stability was discussed. Analog computer fundamentals were introduced. The implications of aggregation, discrete time, and statistical state transitions were analyzed. System decomposition techniques and their implications on modeling and computer simulation were discussed. The concepts of controllability and observability and their relation to generating control strategies were considered.

At the beginning of the seventh week, the students submitted the final modeling report and at the beginning of the tenth week they submitted the final simulation report.

During the ninth and tenth week, each student made an oral presentation to the class describing his problem, his model, and his simulation.

Appendix II presents a detailed syllabus for the course.

Observations and Recommendations

1. The students were not prepared to write a technical proposal. As a result, practically all the students were required to resubmit the proposal describing the modeling and simulation project they wished to undertake. A common failing in the proposals stemmed from a lack of detail necessary to sufficiently specify what the objectives of the project were and what approach to a solution was being proposed. Because of this, it was deemed worthwhile to spend one half hour of class time outlining specifics to be included in the proposal. A proposal outline presented to the students is given in Appendix III. It is recommended that when students have little experience in technical writing an outline should be given to the student at the beginning of the course.

2. The method of grading used, based on the completion of four units of work to earn four points, was strange to the students and, in this case, to the instructor. Although, initially there were apprehensions on both sides, it is felt that the grading system was an important factor in satisfying the course objectives. The grading system is, perhaps, worth recommending on its own merit independent of this course in instances where a student project is to be emphasized.

3. The students continued coming to class after their projects had been completed and their course grades determined. More importantly, all students implemented a computer simulation although they had already earned a B grade in the course without the simulation. This is perhaps the strongest testimonial to both the students' interest in the course and the grading system.

4. Four students of the twenty-four initially enrolled dropped the course, all prior to the date that the written proposal was due. This can be attributed to several factors. Perhaps the most significant was that the students initially did not know exactly what they were getting into. Since this was the first time the course was given, there was no "grapevine" on the course and some of the students were simply not interested in this kind of an involvement.

5. One half of the students rated the course "excellent" and one half of the students rated the course "good" (the other alternatives are "adequate" and "poor") on the standard

course evaluation form which the students fill out for every electrical engineering course they take at Michigan Technological University.

6. Several students had considerable difficulty in generating a project problem. It is felt that this situation would have been considerably alleviated if the course had been offered as a sixteen-week course (semester system) rather than a ten-week course (quarter system); and increasing the number of the credits for the course from three to four or five would also help. Such increases would allow more case studies to be introduced before the student is required to submit his project proposal. Another possibility for students having difficulty generating a project problem would be for the instructor to have a large modeling and simulation problem that he is personally interested in and to subdivide it among those students. Since such an option tends to eliminate an important aspect of the course for the student, it should perhaps be permitted only at the price of a reduced grade. It is emphasized, however, that although there was some awkwardness between several students and the instructor at the time the project proposal was due, the course was quite workable without the proposed option. Further, it is likely that some students might have selected such an option if it were available with no real need to do so.

7. None of the students elected to use the analog computer for their simulation although several students expressed in their final reports that they should have. That this option was not considered initially by any student is attributed to the students' lack of experience with analog computers. The students became aware of the potentials of analog computation only after some detailed demonstrations in class which, unfortunately, came after the students had committed themselves to digital simulation. An earlier demonstration of analog computation would have had greater impact here.

8. Although all the students had a common background in electrical engineering, the variety of subject areas was indeed wide (see Appendix IV). Surprisingly there was no simulation of a purely electrical system; though there were four simulations of electromechanical systems. This suggests that the objective of treating modeling and computer simulation broadly was fulfilled and that an electrical engineering background was not essential to the successful completion of the course.

Conclusions

In terms of the course objective of introducing the students to modeling and computer simulation, the course was a success. Each of the students completed a modeling and computer simulation project and presented their results both orally and in a written final report. As hoped for, the scope of the course was wide both in terms of modeling problems and computer simulation approaches. The classroom approach of starting with a series of case studies and demonstrations and ending with lectures on modeling and simulation theory appeared to be quite effective.

The most important suggestion for improving the course is to increase the number of course credits from three to four or five. If the course is offered on a semester basis, this will be unnecessary. On a quarter system, the increase in credit hours will allow more case studies to be considered and more simulation demonstrations (especially analog computer demonstrations) before the students are required to specify their project problem. It appears, however, that the course is best suited to be offered as a 3-credit semester course, allowing as much as eight weeks for case studies and demonstrations.

APPENDIX I

References Placed on Reserve in Library

1. P. P. Schoderbek (Ed.), *Management Systems*. Wiley, 1967--especially paper "Models" by I. D. J. Bross, pp. 140-149.

2. K. E. F. Watt, *Ecology and Resource Management-- A Quantitative Approach*. McGraw-Hill, 1968.

3. R. M. May, Limit cycles in predator-prey communities. *Science*, 1972, 177.

4. D. I. Elgerd, *Control Systems Theory*, McGraw-Hill, 1967.

5. J. W. Forrester, *Principles of Systems: Text and Workbook*. MIT bookstore, 1968. (Forrester's *Industrial Dynamics*, *Urban Dynamics* and *World Dynamics*, also.)

6. H. T. Odum, *Environment, Power, and Society*, Wiley-interscience, 1971.

7. H. D'Angelo and T. G. Windeknecht, "An Approach to Modeling an Elementary School." *Socio-Economic Systems and Principles*, University of Pittsburgh Press, 1973.

8. D. M. Wiberg, *State Space and Linear Systems*, Schaum Outline Series, McGraw-Hill, 1971.

9. S. Goldberg, *Difference Equations*, Wiley, 1958.

APPENDIX II

Course Syllabus

Class Session	Topics
1	Dynamic systems; introduction to numerical integration and differentiation methods, a comparison
2	Population models (1 species and 2 species predator-prey)
3,4	A broom-balancing model (space booster launching problem)
5,6	Market modeling (an inventory model and a small-business model)
7	An ecology model (the sacred cow in the Indian society)
8,9	The model of six-grade elementary school (non-aggregated, stereotype model: each child and faculty member represented in the model)
10,11	Concept of state and state variables; methods for generating state equations
12	Quiz (on model interpretation)
13	Introduction to analog computer
14	Analog computer simulation for finding state-trajectories (a linear example and a simulation demonstration)
15	Discussion of stable points and limit cycles
16,17,18	Digital computer simulation for finding state-trajectories (a nonlinear predator-prey example, presentation of digital computer simulation outputs, comparison with an actual analog computer simulation, discussion of differences between continuous-time and discrete-time models)
19	Aggregated models vs. nonaggregated models
20	Statistical models vs. deterministic models (The emphasis here is on the implications of systems with stochastic state transitions and not on systems with stochastic inputs)
21	Quiz (on concepts of state and state transitions)
22	System decomposition (input portion, dynamic portion, output portion)
23	Introduction to controllability and observability concepts and their implications in the generation of control strategies
24	Generating simulation inputs
25-30	Student presentations

APPENDIX III

A Possible Project Proposal Format

1. A statement of the objectives of the project (what will you be trying to determine from the final simulation?)

2. Introduction to the background of the problem

   a. A technical history (REFERENCES)

   b. Present state of the art (REFERENCES)

3. The proposed approach to the development of the model

   a. A block diagram of the process to be modeled introducing the variables and subprocesses that are anticipated

   b. A detailed description of proposed approach to developing the relations between the variables in each subprocess (REFERENCES)

   c. Several actual examples of the application of the modeling approaches proposed

   d. Estimate the complexity of the final model:

      (i) How many equations?
      (ii) How many empirical nonlinear relations (graphs, tables, etc.)?
      (iii) How many state variables (integrators, summers)?

   e. What particularly difficult modeling problems can you anticipate? Be specific and technical

4. The proposed approach to the simulation

   a. What machine do you propose to use for the simulation? Why?

   b. If using a digital computer, what language do you propose to use? Why?

   c. How will you generate inputs and initial conditions for your simulation? Be specific and technical

   d. What difficult problems do you expect to encounter in realizing a simulation? Be specific and technical

5. The proposed schedule of work

   This includes a list of deadlines for all distinct phases of the effort. If a group project is proposed, then the proposed division of the project should be included and a schedule for each group member.

6. A comprehensive list of references

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